

Designing the structural support for a front automotive wing for a new race series.

Adam Evans 2005959
ACMA5010



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UNIVERSITY OF WALES TRINITY SAINT DAVID

Adam Evans 2005959

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Introduction

Within the sport of Formula One the car is the biggest factor to winning and losing races, yes drivers place a massive part in it, but the driver can only win if the car is designed to win, and with the modern-day restrictions being applied to the teams, getting the aerodynamics right is key to the team success



Figure 1 - Marelli F1 Car

Failure to engineer the car correctly could result in catastrophic failure and lose the race, this is why it is important to do paperwork exercises, working out what forces each component can handle and prototype testing to ensure what you have designed works.

Main Project

An assignment has been given to the design a structural support for a front wing of a car for a new race series. The information that we know is that the structural section which runs to the end of the wing is 210GPa with a cross section gauge of 2mm. This is assumed to be attached to the vehicle giving it all 6 degrees of freedom and there is a limit to the deflection which is 10mm

Known figures

- 210GPa
- 2mm gauge
- 6 degrees of freedom
- 10mm deflection Limit

To work out the outside diameter for the support, Slope and deflections of beams theory needs to be used.

$$y_{\max} = \frac{-WL^4}{8EI}$$

Using the equation we can work out what I is to move us onto finding the diameter required.

- $y_{\max} = 10\text{mm}$
- $W = 500\text{N}$ loads is typically experienced on the front wing of race car (Groote, 2003)
- $L = 1000\text{mm}$ as shown in Figure 2- Front wing width

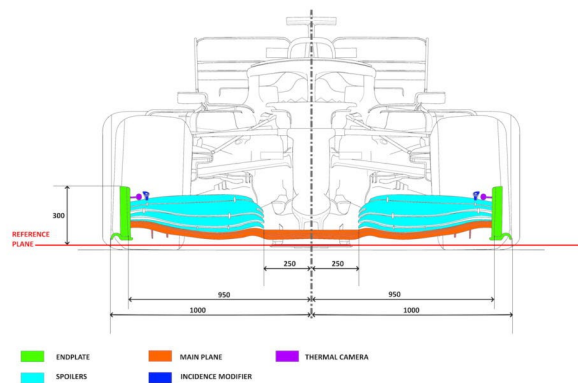


Figure 2- Front wing width

- $E = 200\text{ GPa}$
- I = this is what needs to be worked out by rearranging the above equation.

To use this equation, it firstly needs to be rearranged to make I the output from the equation.

$$I = \frac{WL^4}{\gamma_{\max} 8 E}$$

Figure 3 - Integration to make I the output

From this the values can be added to provide the answer for I

$$I = \frac{(500 \times 1^4)}{(0.01 \times 8 \times 210000000000)}$$

Figure 4- values added to the equation

This gives us a value for the second moment of area know as I

$$I = 2.98E-08$$

Figure 5 - Value for second moment of area

With this value now established it can now be used to work out the diameter required of the hollow tubing with the wall thickness of 2mm.

Using the superposition principle, the second moment area of the outside of the tube can be subtracted from the second moment of area of the inside of the tube to give the second moment of area for the tube.

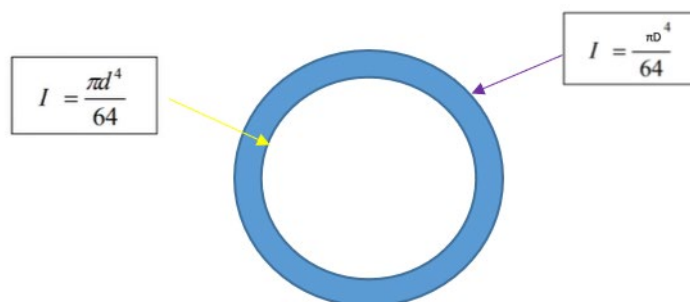
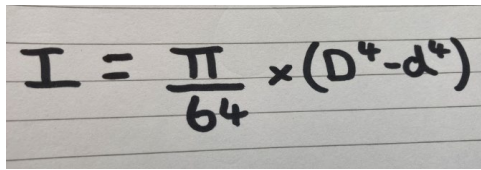


Figure 6 - Cross section of pipe and equations

Simplifying the two equations into one equation.



$$I = \frac{\pi}{64} \times (D^4 - d^4)$$

For this equation to work the diameters needs to be entered which will provide the I value, however as I value has already been established, this equation is going to work in reverse like a fault-finding tool to find the diameter. To make this easier Microsoft Excel program is going to be used where the equation is written, and a set of diameters are inputted, which are not the correct but are an engineered guess. The equation is then dragged down x number of cells and the diameters automatically increase this is done until the desired number is achieved for I, providing the diameter of tubing to be used or if the initial inputted diameters start off above the I value you know they need to be decreased and start the process again.

Calculation to determine the Diameter required			
D(mm)	D(m)	d(m)	I
5	0.005	0.001	3.0615E-11
6	0.006	0.002	6.28E-11
7	0.007	0.003	1.13825E-10
8	0.008	0.004	1.884E-10
9	0.009	0.005	2.91235E-10
10	0.01	0.006	4.2704E-10
11	0.011	0.007	6.00525E-10
12	0.012	0.008	8.164E-10
13	0.013	0.009	1.07938E-09
14	0.014	0.01	1.39416E-09
15	0.015	0.011	1.76547E-09
16	0.016	0.012	2.198E-09
17	0.017	0.013	2.69648E-09
18	0.018	0.014	3.2656E-09
19	0.019	0.015	3.91009E-09
20	0.02	0.016	4.63464E-09
21	0.021	0.017	5.44398E-09
22	0.022	0.018	6.3428E-09
23	0.023	0.019	7.33583E-09
24	0.024	0.02	8.42776E-09
25	0.025	0.021	9.62332E-09
26	0.026	0.022	1.09272E-08
27	0.027	0.023	1.23441E-08
28	0.028	0.024	1.38788E-08
29	0.029	0.025	1.55359E-08
30	0.03	0.026	1.73202E-08
31	0.031	0.027	1.92364E-08
32	0.032	0.028	2.12892E-08
33	0.033	0.029	2.34833E-08
34	0.034	0.03	2.58234E-08

35	0.035	0.031	2.83142E-08
36	0.036	0.032	3.09604E-08
37	0.037	0.033	3.37668E-08
38	0.038	0.034	3.6738E-08
39	0.039	0.035	3.98788E-08
40	0.04	0.036	4.31938E-08
41	0.041	0.037	4.66879E-08
42	0.042	0.038	5.03656E-08
43	0.043	0.039	5.42317E-08
44	0.044	0.04	5.8291E-08
45	0.045	0.041	6.2548E-08

From all the numbers which have been generated the I value of 2.98E-08 can be matched with the nearest whole number of 3.09604E-08 which will give a tube diameter of 36mm.

Automotive front wing development

When talking about a front wing in the automotive sector, the motor sport which first come to mind and are more recognised for having visible aerodynamics in the form of a front wing is a Formula one car. But the cars which you see the likes of Lewis Hamilton or Sebastian Vettel driving these days doesn't resemble the first wing which was mounted onto a formula one car in 1968, although other elements of a front wing had been seen already in other motor sports. (Fagnan, 2018)

The main reason for Formula one wanting to introduce a front wing was the sudden change in engine size from a 1.5 litre engine to a 3 litre naturally aspirated 450Bhp beast. With the car being so small and light it now needed down force to pin it to the road and to allow the power being generated to propel the car forward instead of just spinning the which through loss of traction, and also uncontrollable through conners.

Today's aerodynamics mainly through the front wing of the car is the biggest performance differentiator to allow modern car to reach such high average speeds whilst traveling not just in a straight line but also through corners. (www.autosport.com, 2020)

Comparing the designs shown in Figure 2- 1968 F1 Car Figure 1 -2022 F1 Car



Figure 8- 1968 F1 Car



Figure 7 -2022 F1 Car

Amazing how far the understanding of aerodynamics has moved on, The original design came for a Texan by the name of Jim Hall, he understood the concept that to prevent the loss of traction more

down force needed to be applied to the car sticking it to the driving surface. Realising that a aeroplane wing works in the opposite way as this lift an object away from the surface, if a wing was to be mounted but in a reverse design it would push air downwards. Although this was first mounted on the rear of the car in may I add to today's standards it would look great in a 18 year old max power car meet. This car was known as the Chaparral 2F shown in Figure 3- Chaparral 2F, although not a formula one car it inspired car manufactures and race team engineers to start looking at aerodynamics which worked. (www.autosport.com, 2020)



Figure 9- Chaparral 2F

The first Formula one team which made its aerodynamic debut was Lotus with the Lotus 49B shown in Figure 2- 1968 F1 Car, This car won the Monaco GP in 1968 and since then the development of aerodynamics has continued to change on a yearly basis (www.amalgamcollection.com, 2022)

When looking at the design of the front wing on modern day formula one cars they resemble nothing like an aeroplane wing as they did back in 1968

“The front wing of a Formula 1 car is without doubt the most complex aerodynamic device in race car design.” (www.totalsimulation.co.uk, 2016)

The front wings today will generate up to 40% of the cars down force which could exceed two time the weight of the formula one car, but this is dependent on the course which the car is going to be driven on. For example, Monaco is a very tight and windy street course but Silverstone is open with long high-speed straights, all the features are shown in Figure 4 - Front Wing set up where altering these can change the downforce which is required.

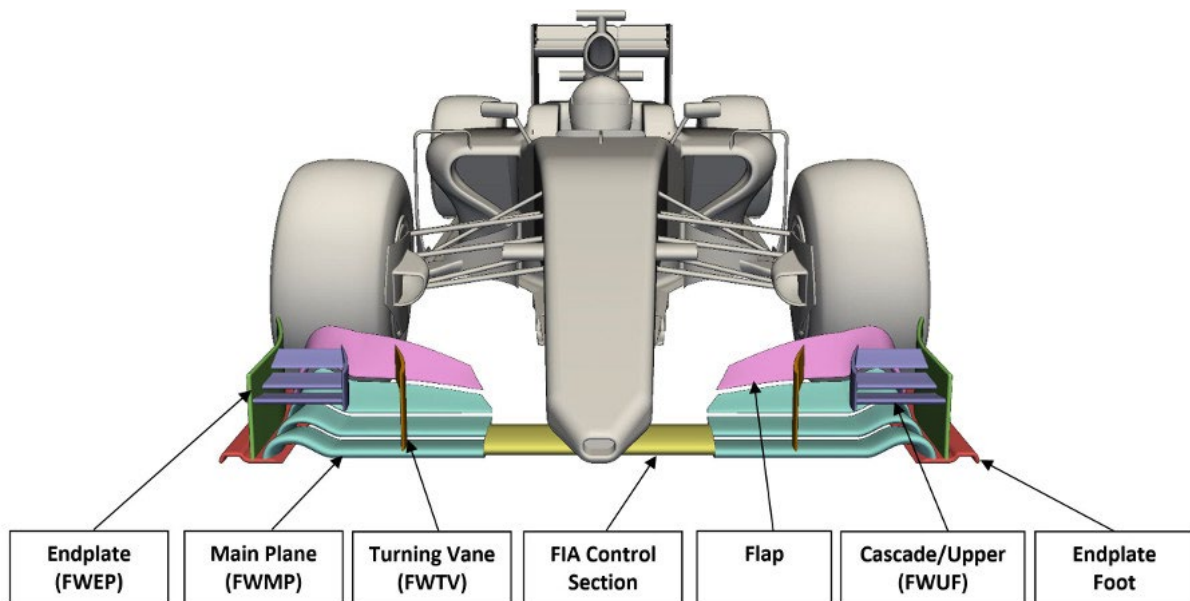


Figure 10 - Front Wing set up

This now means that from where cars didn't have front wings in 1968 on modern cars their design and set is now essential to the team success.

Going forward with all the restrictions which are in place with formula one, the evolution of the front wing needs to progress and will be one of the winning or losing factors on the car, but like the rear wing and I think the front will be able to have pre-set configuration to allow extra down force for over taking or taking corners tighter, but this will only be available for x amount of time during the race.

Manufacturing process of Front wings

The materials used in the manufacturing of the front wing must not only be able to withstand downforce equivalent of two times the cars weight, but they must also provide optimum driver safety. Technological advancements in materials from those used in the Lotus 49B formula one car have enabled engineers to create a car which lighter , safer and faster in modern day racing.

Looking at Figure 5 -Materials properties graph, the material needs to have all three main characteristics – Light weight, strong and stiff

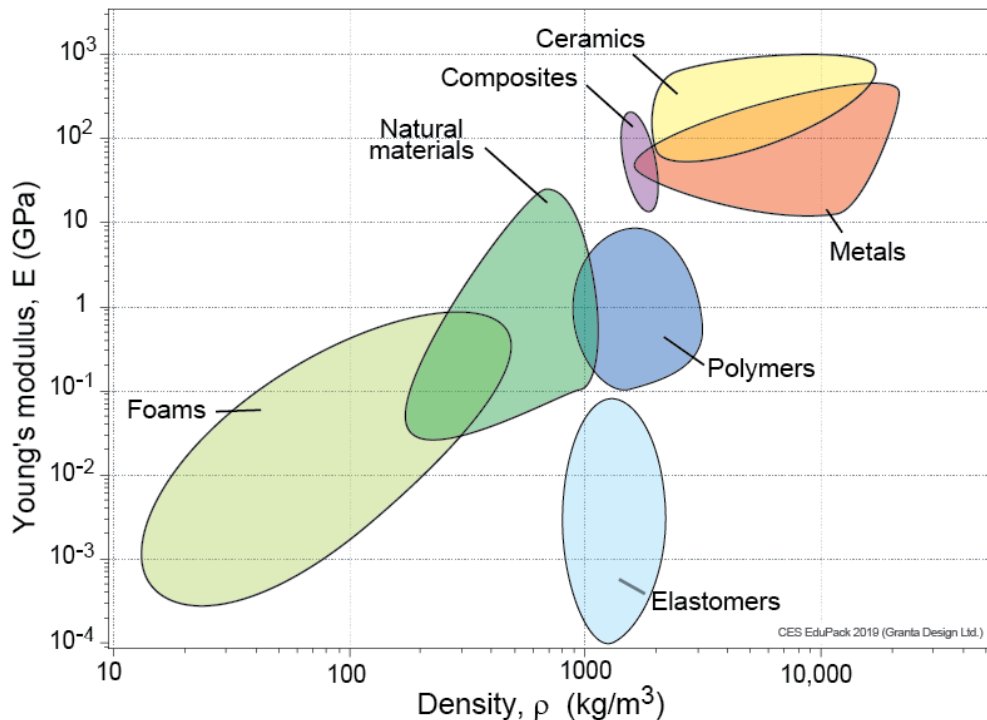


Figure 11 -Materials properties graph

This focuses the engineer's attention to the top right-hand side of the graph which includes, composites, ceramics, and metals. But only one of these ticks all the boxes which the engineers are after, and this is composites.

Although metals are strong, the weight of them has a negative impact when comparing them against a composite of similar strength, as the metal can weight up to 40% heavier. As for ceramics the ductile nature of them would cause them the break very easily and with the combination of they weight it rules them out very quickly.

Within the category of composites sits carbon fibre which has the highest strength and stiffness per density than metal or any other material (SMI Team, 2022)

The first reinforced composite components were first used on a formula one car in 1980 by the McLaren formular one team. With modern cars being made up of about 85% of carbon fibre components. (Thomas, 2013)

With the material selected working with it to produce a wing isn't as easy as machine a part out of a block of steel. With carbon fibre there are three main methods to creating the desired part

- **Wet layering** – is like a making a sandwich out of the layers of fiber , with a resin being applied to hold the sheets together. However, this method requires a lot of skill to create high quality parts. Figure 6- Wet Layering
- **Prepreg Lamination** - With this method the fibre is infused with resin and then placed into a mould where heat is applied when the mould tool is closed to active the resin. This method is precise and repeatable, but also a very expensive methos used for High-performance application like formular one car parts. Figure 7- Prepreg Lamination

- **Resin transfer moulding** -similar method of using a mould tool but with this method resin is forced into the cavity at high pressure. This method is good for high volume manufacturing.
Figure 8- Resin Transfer Moulding

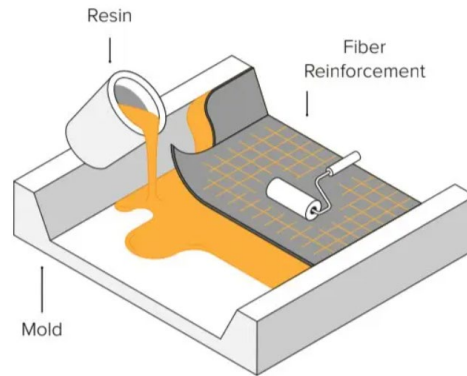


Figure 12- Wet Layering

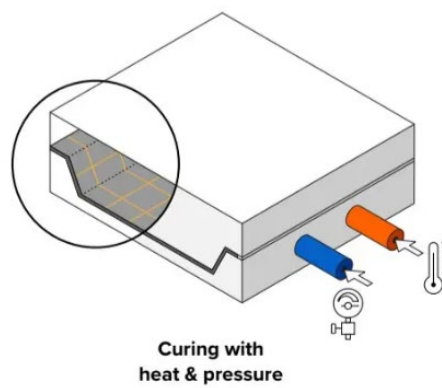


Figure 13- Prepreg Lamination

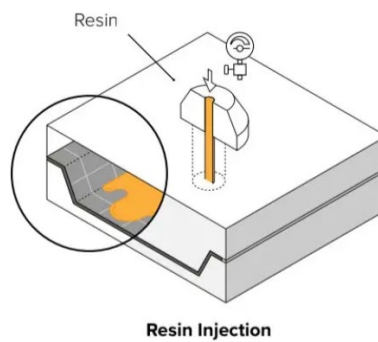


Figure 14- Resin Transfer Moulding

(formlabs, n.d.)

Prototype testing

Knowing that the size of tube which is going to be used is 36mm and the material it is going to be made from is carbon fibre, a method of prototyping can now be developed and used to test the part under extreme conditions in a safe environment.

The first testing which is to be done before any parts are manufactured is CAE analysis, this requires the part to be drawn up using a CAD software package and using the numbers which have been used to determine the external diameter of the tube can be applied to the part. The CAE analysis will show which areas are subjected to the highest force (Figure 14 - CAE analysis on a F1 car) and what levels of strain is received in the area, and from this a judgment can be made if the tube and the material which has been selected is okay to progress on prototype stage.

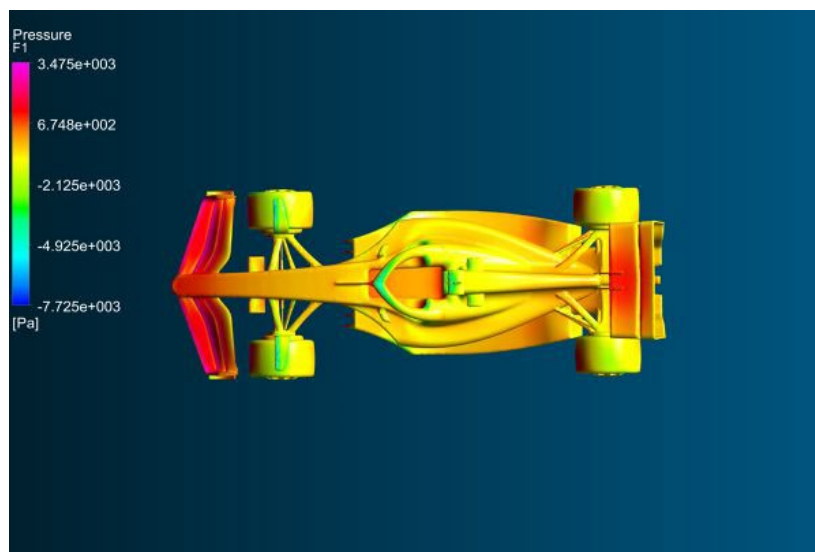


Figure 15 - CAE analysis on a F1 car

The prototype stage would require a one-off part to be manufactured which would allow physical testing of the part within a climatic wind tunnel, the reason for selecting this over a normal wind tunnel is that the prototype can be subjected to range of different elements which as formula one a sport travels all around the world the air temperature, humidity and road temperature can change. So, the front wing needs to be able to withstand all of these whilst being subjected to stress and strains.

A climatic wind tunnel testing facility can produce the following

- Air temperature -40 to + 55°C
- Humidity range of 5% to 95% relative humidity
- Air speed of Primary = 150km/h Secondary = 200km/h
- Underbody heating up to 30°C above chamber temperature

(Mira, 2022)

This environment and wind tested would need to be captured in the form of data, which can be analysed to understand what is happening at each stage of the testing. For this strain gauges can be mounted in key areas to provide real feedback to how the support structure is performing.

All this analysis will provide relative information which will be used to allow the front wing and the support to be made and hopefully go on to win races for the team.

Conclusion

Working out the size of diameter to be used to create the support for the front wing to be 36mm at the start of the report, allowed us to progress into material selection and the understand of the method of applying the material to the application. But at the same time knowing that the material selected must withstand the load that in real world racing would not be uniformed as implied in the equation used.

This information would be fed into the CAE analysis where the material properties can be selected along the diameter tube. Following on the CAE analysis a prototype could be manufactured allowing climatic wind tunneling testing to take place. From this result the finished product could be manufactured and allowed to race knowing it meets the spec which was desired.

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